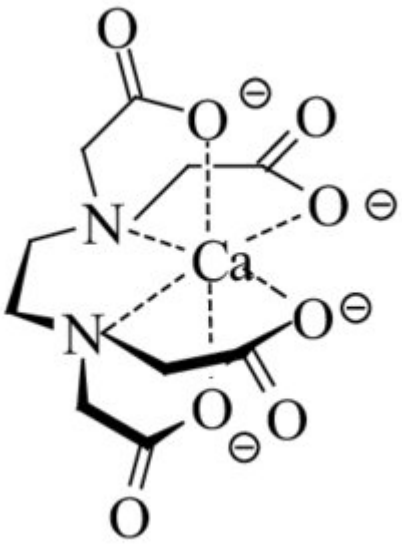
Calcium EDTA and its problems in hydroponics

Calcium is mainly used in hydroponics as calcium nitrate, given that this is a very soluble and abundant form of calcium. However this is not the only way calcium can be fed to plants and a myriad of other calcium sources exist. Among this we find calcium sulfate, calcium chloride, calcium hydrogen phosphate, calcium citrate, calcium gluconate and calcium EDTA. This last form, a chelate of calcium with EDTA, is one of the most cheaply available forms of chelated calcium but carries with it some substantial problems in hydroponic culture. In this article we are going to talk about Ca EDTA, its advantages and challenges when used as a supplement for calcium in hydroponics.



Model representation of the $CaEDTA^{-2}$ anion in the Ca EDTA salt.

When talking about Ca EDTA we should first understand that this is not simply a calcium ion with an EDTA molecule wrapped around it. In reality, the product we purchase as Ca EDTA, that contains 9.7% Ca by weight, is actually represented chemically as $C_{10}H_{12}O_8CaN_2Na_2 \cdot 2H_2O$. The Ca EDTA product is

actually four parts, a few waters of crystallization, the Ca^{+2} cation, the chelating agent anion that wraps around it ($EDTA^{-4}$) and two sodium cations, Na^{+}, that are used to counter the two excess negative charges coming from the Ca EDTA (which we should more accurately call $(CaEDTA)^{-2}$). When adding Ca EDTA we are actually adding four things, a little water, Ca, EDTA and Na. Most importantly Ca EDTA is in reality 12.15% sodium, meaning you're adding more Na than you're adding Ca when you use it.

Because of the above, thinking about Ca EDTA as any significant portion of a plants Ca nutrition is going to be a problem. Adding 100 ppm of Ca through this chemical would imply adding more than 100 ppm of Na. This addition of sodium can start to be heavily detrimental to plants as higher and higher values are reached (read my article on sodium in hydroponics to learn more). Although there is not much in the way of scientific literature using Ca EDTA, we do find some reports talking about heavy toxic effects at concentrations near 2.5 mM (940.7 ppm), which would contribute around 90 ppm of Ca to a solution.

Another important aspect to consider is the EDTA molecule itself. The EDTA chelate is not passive by any means and is not covalently attached to the Ca, so can easily move away. Since it binds pretty weakly with Ca, it will want to exchange Ca with anything else that seems more attractive to it. This poses an important problem when applying it in solution, as the EDTA in Ca EDTA might dissociate from Ca and attach to another ion that it finds more attractive, it prefers heavy metals so this can actually cause extraction of things like lead from the media. This might be an important consideration when used in cases where the media might contain significant amounts of heavy metals.

Yet another interesting issue – that I haven't seen mentioned

anywhere else and only know experimentally – is that the actual $CaEDTA^{-2}$ anion can form insoluble salts with Ca itself. This means that you can actually precipitate Ca(CaEDTA) in solutions that are highly concentrated in both ions. This is an important reason why concentrated solutions of Ca EDTA and Ca nitrate are very hard to prepare right, because as soon as you pass the solubility limit of Ca(CaEDTA) you will start to see it crystallize out of solution. Many people wonder why something is precipitating out of a solution made of two very soluble Ca salts, the reason is that Ca EDTA is not a neutral entity but can actually form a salt with free Ca. The Ca EDTA definitely requires its own concentrated solution most of the time.

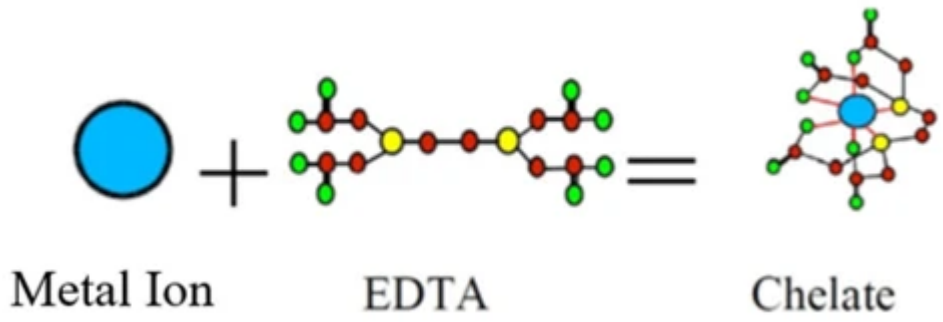
So why would anyone use CaEDTA given the above set of very important problems? There are a some advantages to it that make it a good salt for some applications, particularly foliar sprays. The first is that it is not going to precipitate easily out of solutions because of anions, so it can remain at a high concentration with anions that would normally precipitate as Ca salts in the presence of free Ca. This can be interesting in the case of some anions, like salicylates, that are often used as plant growth promoters (you can see this specific use in this paper). It is also one of the only forms of Ca that is taken in by the plant as an anion, so it is Ca that can get into the plant without having to compete with other cations in their transport channels. There are therefore some cases where Ca can be used very successfully in foliar applications (1).

Although there might be some niche applications for CaEDTA, particularly allowing some experiments that would be impossible with regular Ca salts, there are also some very important issues with its use in hydroponic culture. If you're contemplating using it, I would suggest you carefully consider its chemistry in solution and interactions with other substances that will be with it, particularly in stock

solutions. You should also consider the amount of sodium being added and preferably avoid using it in feeding solution applications unless you have carefully considered all of the above and its advantages are more important for your particular use case.

How to prepare a low cost chelated micronutrient solution

Micronutrients constitute only a small portion of a plant's nutritional requirements but are still vital to growth and development. They are mainly comprised of heavy metals (Fe, Zn, Mn, Cu, Mo) as well as a single non-metal, boron (B). Since they are used in such small concentrations – normally in the 5 to 0.01 ppm range – they are normally put into concentrated nutrient solutions in small proportions and included with other components such as Ca and Mg, which are present in concentrations much more in line with macro nutrients like N, P and K.



Simple model of the metal chelating process

The advantage of micro nutrients is that they are available

cheaply and in high purities as heavy metal sulfate salts. These however have the problem of leading to relatively unstable cations in solution, making the preparation of concentrated micro nutrient solutions with pure sulfates impractical (unless you want to see how a gallon of rust looks like). However we can chelate the cations as they come out of these sulfates, using a chelating agent, in order to prevent any precipitation issues. In this article I am going to walk you through the preparation of a DIY chelated micronutrient concentrated solution. This is much cheaper than buying the heavy metal chelates, which can be 3+ times more expensive. To prepare this solution you'll need to buy the chemicals shown in the table below. The table includes links to buy all the different substances mentioned plus their cost (without shipping).

Link	Price USD/lb	Weight g/gal
Disodium EDTA	22.96	17.0600
Ferrous sulfate heptahydrate	15.99	9.4211
Zinc sulfate monohydrate	9.49	0.1039
Manganese sulfate monohydrate	14.99	1.1646
Copper sulfate pentahydrate	20.99	0.0595
Sodium Molybdate	19.99	0.0191
Boric acid	10.95	3.3384
Total Cost	115.39	

List of salts to prepare a DIY chelated micronutrient concentrated solution. This concentrated solution is to be used at 5mL per liter of final feeding solution.

In order to prepare the solution you also need a scale that can weight with a precision of +/- 0.001g (this is my low cost recommendation) and a container where you can store 1 gallon of solution. Please note that these solutions *have to be prepared with distilled water*, with RO water you might still run into some issues in the process. To prepare the solution carry out the following steps (the weights to be used are

specified in the table above):

1. Wash your container thoroughly with a small amount of distilled water
2. Fill your container with half its volume of warm distilled water (30C, 86F)
3. Weight and add the disodium EDTA, stir until it is completely dissolved (this can take a while).
4. Weight and add all the remaining micro nutrients one by one in the order given above, stirring till each one is fully dissolved before adding the next.
5. Fill the container to its final volume using warm distilled water.
6. Let the solution cool before closing the container.
7. For longer half-life transfer to a container that is opaque to UV light.

This solution is prepared to give you the heavy metal concentrations of the Hoagland nutrient solution (a very common set of ratios used in scientific research for growing plants) when used at a ratio of 5mL per every liter of final feeding solution (18.92mL per gallon). The links given above are for 1lb of each product, with this you should be able to prepare at least 53 gallons of the concentrate, which will allow you to prepare 10,600 gallons of final feeding solution. The first salt you will run out of is Fe, but some are used so sparingly that you should be able to use them for the rest of your life without needing to buy any more (like copper sulfate and sodium molybdate). For less than 120 USD you will be able to have enough solution for probably the rest of your life – if you're a hydroponics aficionado – or even an entire crop cycle if you're a commercial grower.

This preparation is not without problems though, since the chelates are all prepared *in situ* they will take a substantial amount of time to reach their thermodynamic equilibrium, meaning that it cannot be used to soon or some of the metals might not be fully chelated. To obtain the full metal

chelating effect an excess of around 25% of disodium EDTA is also used, which means that this micro nutrient solution contains more free EDTA than a solution prepared with the chelates. Another issue is that all heavy metals are chelated with EDTA, which might not be optimal depending on your growing conditions. The EDTA chelates are also less stable against UV light and are also more easily attacked by oxidants. Another final issue is that the solution above contains no preservatives and fungi generally like to feast on this sort of micronutrient containing solutions. It is therefore reasonable to avoid preparing any large amounts of the above, as a solution prepared as instructed is normally expected to spoil in 3-4 weeks.

With this in mind, the above is not a perfect but a low cost and practical solution for those who want to start preparing their own nutrient solutions and avoid paying the high prices of some commercial nutrients just because of their micro nutrient contents. The above gives you a versatile micro nutrient concentrate that is bound to be adequate for growing almost all plants.

Is my water source good for hydroponics?

Before starting your hydroponic project it is important to know whether your local water source can actually be used to water plants. Not all water sources are compatible with plants and some require special adaptations to the nutrient solution in order to become viable. In this post I will talk about the things that can make a water source unsuitable for hydroponics and the sort of modifications that would be required to make

these water sources work with plants. The main points in the post are summarized in the diagram below.

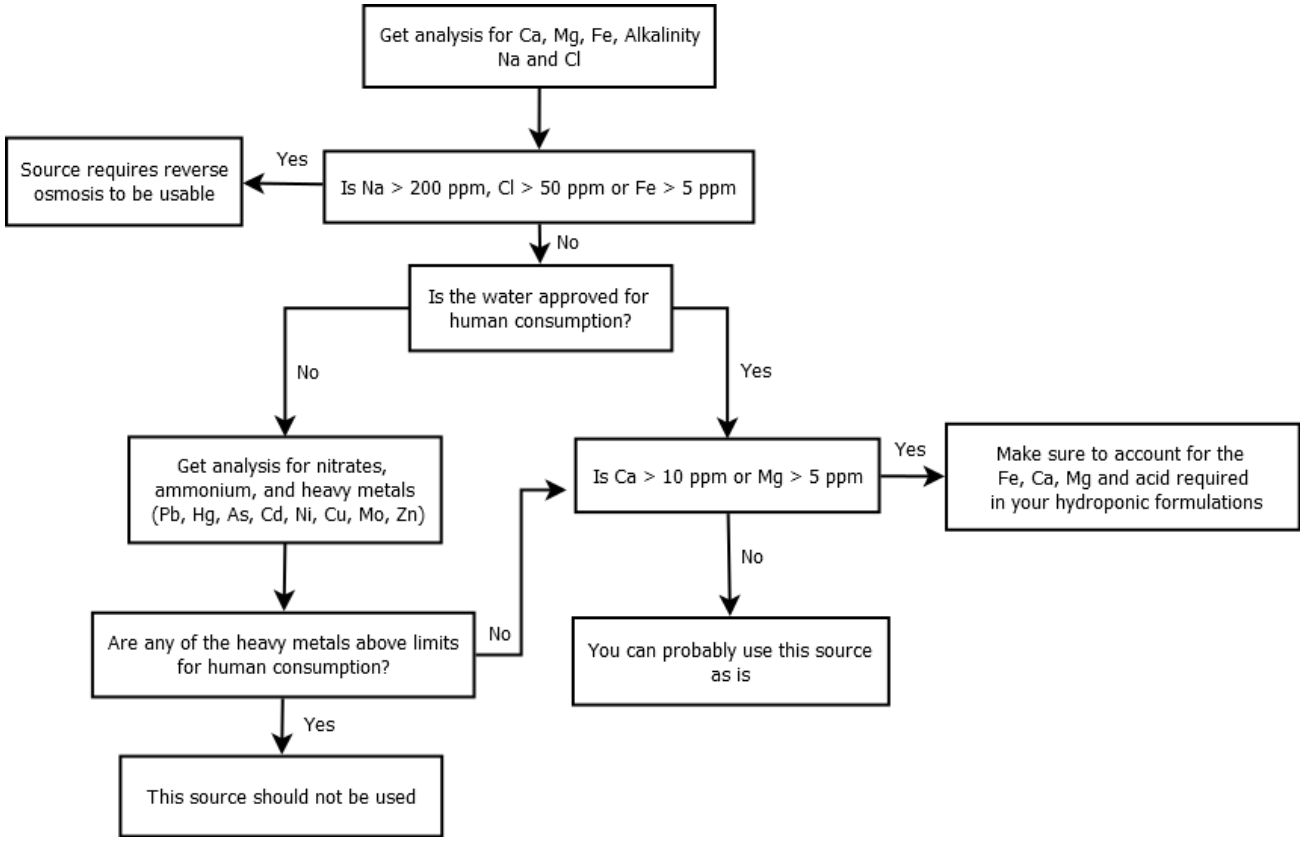


Diagram to figure out if your water can or cannot be used in hydroponics

Tap and well water sources can contain different substances characteristic of the natural environment where the water originated. Water that goes through rocky formations containing a lot of limestone will contain high amounts of calcium and carbonates, while water that goes through dolomitic rock will contain significant amounts of magnesium as well. Water that contains high amounts of Ca or Mg is not necessarily problematic and can be dealt with by adapting the nutrient solution to account for these ions, you can read more about hard water and its use in hydroponics by reading my previous post on the subject. These water sources usually need a significant amount of acid to reach the 5.5-6.5 range, so accounting for the nutrient contribution of the acid in the nutrient formulation is also fundamental.

The most problematic water sources will contain high amounts

of either sodium or chlorides, two ions that we cannot deal with easily in hydroponics and that can be specially bad for plants. You can read more about sodium in hydroponics here, and chlorides and hydroponics here. Sodium concentrations below 200 ppm can be manageable, but any higher concentrations will invariably lead to issues in hydroponics. Chlorides are even more harmful with the threshold for problems at just 50 ppm. Iron can be similarly problematic as sources that contain high amounts of Fe can be incompatible with plants and the Fe can be difficult to remove. This is why the first step in analyzing a water source should always be an analysis including Na, Cl and Fe. If the values are too high then this water source will require reverse osmosis to be usable.

If Na, Cl and Fe are within limits then we can ask the question of whether this water source is approved for human consumption. If it is then we know that the amounts of heavy metals within it should be low, as well as the amount of other ions, such as nitrate and ammonium. If the water has not been approved by a utility company for human consumption then we need to do heavy metal and nitrate/ammonium analysis to figure out if this is actually safe to use. In some cases well water sources can be perfectly fine to grow plants but the products might be contaminated with heavy metals that make them unsuitable for human consumption.



If a water source is within limits for all of the above then we should take into consideration whether we need custom

formulations or whether we can get away with using commercially available hydroponic products “as is”. For sources that have relatively low amounts of Fe, Ca and Mg this is usually a possibility but for sources that have quantities of Fe above 2.5 ppm, Ca above 10 ppm or Mg above 5 ppm, it is advisable to go with a custom formulation that can account for the amount of minerals already present within the water. This can still mean using commercially prepared fertilizers only that the mixing ratios and schedules need to be adapted to manage what is already present in the water, so significant deviations from the manufacturer suggestions are to be expected.

Another important point is that none of the above accounts for potential biological activity within the water, which can be a big source of problems in plant culture. *For this reason always make sure to run the water through carbon filtration and have in-line UV filters to ensure that no bacteria, viruses or fungal spores get to your plants through your water source.*

A guide to different pH down options in hydroponics

The control of pH in hydroponic nutrient solutions is important. Plants will tend to increase the pH of solutions in most cases – as nitrate uptake tends to dominate over the uptake of other ions – so most growers will tend to use pH down much more than they use pH up. While most growers prefer to use concentrated strong acids, there are a wide variety of different choices available that can achieve different outcomes at different cost levels. In this post I want to talk

about different pH down options in hydroponics, along with some of their advantages and disadvantages.



Hydrangeas change color as a response to different pH values in soil

The first group of pH down chemicals are strong acids. These are technically acids with very low pKa values, meaning they react instantly with water to generate at least one mole of hydronium for each mole of added acid. They offer the strongest ability to drop pH per unit of volume, which makes them more cost effective. However the fact that they often need to be diluted to make the pH addition process practical – because of how much the concentrated forms can change pH – can make their use more difficult than other forms of pH down. These are the most common options:

Phosphoric acid (from 20 to 85% pure): This acid doubles as a plant nutrient, meaning plants will be affected by the phosphorus added. It is commonly used in food – so food grade phosphoric acid can be bought cheaply – it also has additional deprotonations with strong buffering at a pH value of 7.2 with buffering capacity against bases getting stronger as the pH goes down all the way to 6.2. This is the most commonly used acid by hydroponic growers.

Sulfuric acid (from 20 to 98% pure): This acid is commonly used in car batteries and offers the largest pH dropping ability per unit of volume among all the strong acids. It is

however important to use food grade sulfuric acid in hydroponics as normal battery acid can include some metallic impurities – from the fabrication process of sulfuric acid – that might negatively affect a hydroponic crop. Food grade sulfuric acid is safe to use in hydroponics. A big advantage is that plants are quite insensitive to sulfate ions – the nutrient provided by sulfuric acid – so adding sulfuric acid does not really affect the nutrient profile being fed to the plants. Note however that most battery acid products in developed countries are also ok, as the quality of these acids demands the metallic impurities (more commonly iron) to be quite low. If in doubt, you can do a lab test of the sulfuric acid to see if any impurities are present.

Nitric acid (from 30-72% pure): This acid also provides nitrate ions to plants, so it also contributes to a solution's nutrient profile. It is however more expensive than both phosphoric and sulfuric acids and more heavily regulated due to its potential use in the fabrication of explosives. The acid itself is also a strong oxidant, so storage and spillage problems are significantly worse than with phosphoric and sulfuric acid. Although this acid can be used in hydroponics, it is generally not used by most growers due to the above issues.

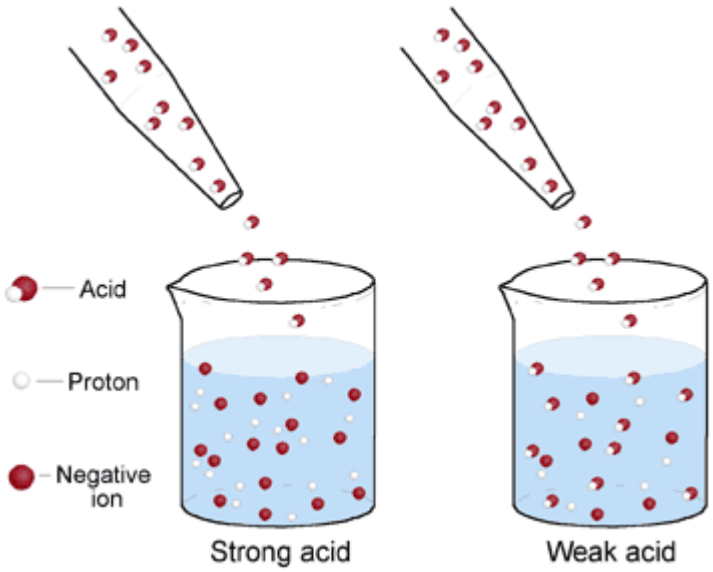


Diagram showing the dissociation of a strong vs a weak acid

The second group of pH down chemicals are weak acids. These are acids that do not generate at least one mole of hydronium ions per mole of acid when put in solution, but do provide a pH down effect as some hydronium ions are generated. This means that larger additions will be needed to cause the same effect but at the same time their handling is usually much safer than for strong acids. Here are some options that could be used as a pH down.

Common food grade organic acids (citric acid, acetic acid, etc): Organic acids are a very low cost way to lower the pH of a hydroponic solution as many of these are available off the shelf in super markets in food grade qualities. The main issue with organic acids – which anyone who has used them has probably experimented – is that the effect of the acids does not seem to hold (pH goes up quickly after the acid is added and the solution comes into contact with plants). This is actually caused by the fact that plants and microbes can actually use the conjugated bases of these ions nutritionally, causing an increase in pH when they do so. The initial addition of say, citric acid, will drop the pH – generating citrate ions in the process – these will then be absorbed by microbes and plants, increasing the pH again rapidly. *The use of these acids is therefore not recommended in hydroponics*.

Monopotassium phosphate (MKP): This salt contains the first conjugate base of phosphoric acid and is therefore way less acidic than it's full on acid partner. Since it's a solid its addition is way easier to control compared to the acid and it can also be handled safely with minimal precautions. It provides both potassium and phosphorous to a solution – both important nutrients – and therefore needs to be used carefully when used as a pH down agent (as it significantly affects the nutrient profile of the solution). Since it adds both a cation that helps counter pH increases by plants and phosphate species it provides a double buffering effect against future pH increases. It is a very common ingredients of commercial pH

down solutions for this reason.

Monoammonium phosphate (MAP): Similar to the above, except for the fact that this salt adds nitrogen as ammonium, which is a nitrogen form plants are very sensitive to. Plants will uptake ammonium preferentially over any other cation, so MAP provides a very strong buffering effect against nitrate absorption, with potential problems if too much is used (although this depends on the plant species being grown). When MAP is used as a pH down its addition therefore needs to be carefully controlled in order to avoid excess usage. Due to the presence of this powerful ammonium buffer, MAP is generally very effective at preventing future increases in pH, although this might be at the expense of yields or quality depending on the crop.

Potassium bisulfate: This salt contains the first conjugate base of sulfuric acid and is therefore a powerful tool to decrease the pH of a solution. The resulting sulfate ions provide no chemical buffering effect, so the only buffering effect in terms of plant absorption comes from the addition of potassium ions, which can help mitigate nitrate absorption. This salt is also considerably expensive compared with the two above – which are commonly used fertilizers – and is therefore seldom used in hydroponics.

Which is the best pH down solution? It depends on the characteristics of the growing system. Generally a pH down solution needs to be easy to administer, cheap and provide some increase in buffering capacity overtime – to make additions less frequent – so the pH down product or combination of products that best fits this bill will depend on which of the above characteristics is more important for each particular user.

People who use drain-to-waste systems usually go for stronger acids, since they only adjust pH once before watering and then forget about the solution. This means that additional

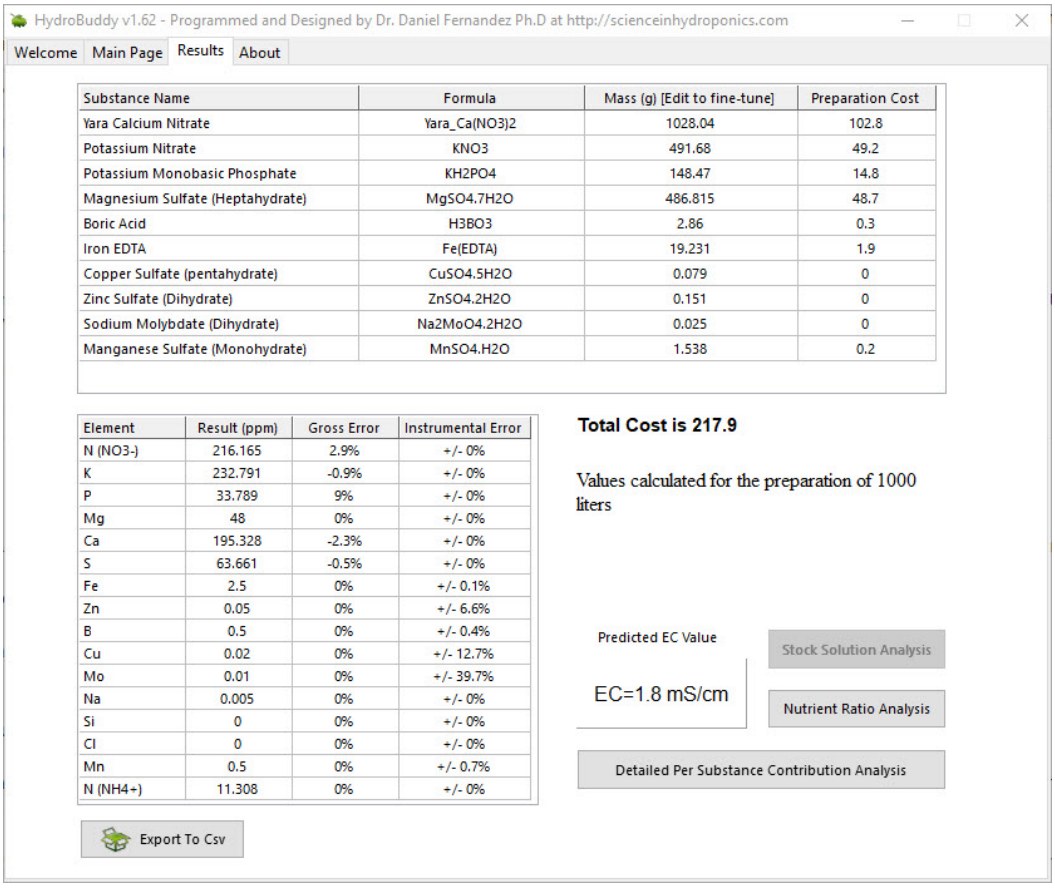
buffering capacity in the solution is probably not going to be very important and cost is likely the most important driving factor. If injectors are used then the strong acids are often diluted to the concentration that makes the most sense for them and most commonly either phosphoric or sulfuric acids are used.

For growers in recirculating systems options that adjust pH with some added buffering capacity are often preferred, because the same solution is constantly subjected to interactions with the plants. In this case it’s usually preferred to create a mixture of strong and weak buffering agents so that both quick decreases in pH and some increased protection from further increases can be given to the solution. In automated control systems using something like a concentrated MKP solution is preferable over any sort of solution containing phosphoric acid, as issues from control failures are less likely to be catastrophic.

Nutrient solution conductivity estimates in Hydrobuddy

People who use Hydrobuddy can be confused by its conductivity estimates, especially because its values can often mismatch the readings of conductivity meters in real life. This confusion can stem from a lack of understanding of how these values are calculated and the approximations and assumptions that are made in the process. In this post I want to talk about theoretically calculating conductivity, what the meters read and why Hydrobuddy’s estimations can deviate from actual

measurements.



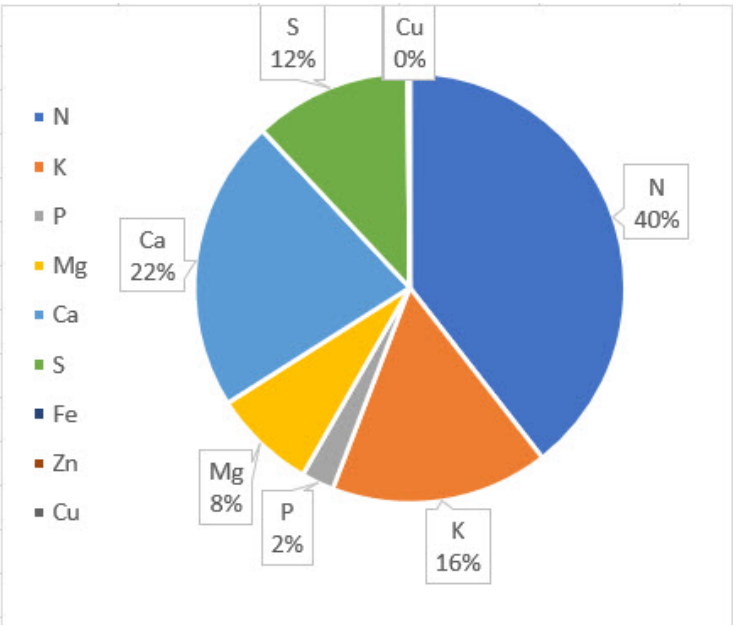
Standard Hoagland solution calculation using HydroBuddy with a set of basic chemicals.

The images above show the use of HydroBuddy for the calculation of a standard Hoagland solution for a 1000L reservoir. The Hoagland solution's recipe is expressed as a series of elemental concentrations, all of them in parts per million (ppm) units. The results show that the final conductivity of this solution should be 1.8 mS/cm but in reality the conductivity of a freshly prepared full strength Hoagland solution will be closed to 2.5mS/cm. You will notice that HydroBuddy failed to properly calculate this value by an important margin, missing the mark by almost 30%. But how does HydroBuddy calculate this value in the first place?

Conductivity cannot be calculated by using the amount of dissolved solids in terms of mass because charges are transported per ion and not per gram of substance. To perform a conductivity calculation we first need to convert our

elemental values to molar quantities and then associate these values with the limiting molar conductivity of each ion, because each ion can transport charge differently (you can find the values HydroBuddy uses in the table available in [this article]). This basically means we're finding out how many ions we have of each kind and multiplying that amount by the amount each ion can usually transport if it were by itself in solution. The sum is the first estimate in the calculation of conductivity.

	ppm	M	mS/cm
N	210	1.49E-02	1.06E+00
K	235	6.01E-03	4.42E-01
P	31	1.00E-03	6.61E-02
Mg	48	1.97E-03	2.09E-01
Ca	200	4.99E-03	5.94E-01
S	64	1.99E-03	3.18E-01
Fe	2.5	4.48E-05	4.84E-03
Zn	0.05	7.64E-07	8.07E-05
Cu	0.02	3.14E-07	3.37E-05
		Total	**2.70E+00**
		HB Guess	**1.8E+00**



Conductivity calculations carried out by HydroBuddy, also showing conductivity contributions per ion. This is done by converting ppm quantities to moles, then multiplying by limiting molar conductivity values here.

The image above shows the result of these calculations for an example with a perfectly prepared Hoagland solution. You can see that the estimate from limiting molar conductivity is initially 2.7 ms/cm – much closer to the expected 2.5 mS/cm – but then HydroBuddy makes an additional adjustment that lowers this down to 1.8 mS/cm. This is done because limiting molar conductivity values make the assumption of infinite dilution – what the ion conducts if it were all by itself in solution – but in reality the presence of other ions can decrease the actual conductivity things have in solution. HydroBuddy accounts for this very bluntly, by multiplying the result by

0.66, in effect assuming that the measured value of conductivity will be 66% of the value calculated from the limiting molar conductivity values. This is of course wrong in many cases, because the reduction in activity due to the presence of other ions is not as strong. However it can also be correct in many cases, primarily depending on the substances that are used to prepare the formulations and the ratios between the different nutrients.

In my experience HydroBuddy tends to heavily underestimate the conductivity of solutions that receive most of their conductivity from nitrates, as this example, but it tends to do much better when there are large contributions from sulfate ions. When I first coded HydroBuddy all my experiments were being done with much more sulfate heavy solutions, so the correction parameter value I ended up using for the program ended up being a bad compromise for solutions that deviated significantly from this composition. With enough data it might be possible to come up with a more advanced solution to conductivity estimations in the future that can adjust for non-linear relationships in the conductivity and activity relationships of different ions in solution.

If your measured conductivity deviates from the conductivity calculated in HydroBuddy you should not worry about it, as HydroBuddy’s values is meant to be only a rough estimate to give you an idea of what the conductivity might be like but, because of its simplicity, cannot provide a more accurate value at the moment. The most important thing is to ensure that all the salts, weights and volumes were adequately measured in order to arrive at the desired solution.

Sugars in hydroponic nutrient solutions

Carbohydrates are an integral part of plants. They produce them from carbon dioxide, requiring no additional external carbon inputs for the process. However, since plants can absorb molecules through their leaves and roots, it is perhaps natural to wonder whether they could also get carbohydrates through the roots and avoid some of the stress they go through in order to produce these molecules from scratch. If plants can uptake sugar and we feed them sugars then will we get fruits with more sugars and bigger plants? It's an interesting question that I will try to answer within this post, looking at the potential use of simple sugars within hydroponic nutrient solutions.



Simple table sucrose

Although the above idea sounds straightforward, it hardly has any interest in the scientific literature or the commercial hydroponic industry. You will find no significant number of research papers studying the use of sugars – simple or complex – in hydroponic nutrient solutions and very few studies looking at sugar uptake and the interactions of *in-vitro* plant tissue with simple sugars. *This lack of interest and use is no accident, it comes from an already established understanding*

of plant physiology and the realization that it is not cost effective, useful or needed to add sugars to nutrient solutions.

Let us start with what we know about the subject. We know that plants exude very significant amount of sugars through their root systems and we also know that they can re-uptake some of these sugars through their roots (see here). From this paper it seems that maize plants could uptake up to 10% of the sugars they exude back into their root systems, which implies that some exogenous sugar application could find its way into plant roots. Even worse, transporting this sugar up to the shoots is extremely inefficient, with only 0.6% of the sugar making it up the plant. This tells us that most of the sugar is wasted in terms of plant usage, a large majority never makes it into the plant and the little amount that makes it actually never goes up the plant. *Plants are simply not built to transport sugars in this manner, they evolved to transport sugars down to roots and to fruits*.

But what about the roots? Given that the plant tissue that would be in direct contact with the sugar is the roots, it is logical to think about positive effects affecting them primarily. We have some studies about the influence of sugar solutions in seedlings (like this one) which does show that sugars can stimulate the growth of new root tissue in very small plants. However in large plants most of the sugar content in the roots will come from transport from the higher parts of the plant and the local sugar concentration will be low. Seedlings can likely benefit from sugars in the roots because leaves are producing very little at this time but larger plants are unlikely to benefit from this effect.

There is however one effect that sugars have that is very clear, they feed the rhizosphere around the plant's roots. Although plants try to care about this themselves – by exuding an important amount of sugars and organic acids – an exogenous sugar addition would most likely boost the amount of microbes

around plant roots (both good and bad ones). The profile of sugars and acids exuded by plants is most likely tuned by evolution to match the microbes that are most beneficial to it and an unintended and negative effect of sugars is to boost all microbe populations at the same time, regardless of whether they are good or bad for the plant. This also increases oxygen demand around roots – because aerobic microbes will want to oxidize these sugars – reducing the amount of oxygen available to plant roots. For this reason, any application of a sugar to a nutrient solution requires the inoculation of the desired microbes beforehand, to ensure no bad actors take hold. It also requires the use of a media with very high aeration, to prevent problems caused by oxygen deprivation.

Sadly there aren't any peer reviewed papers – at least that I could find – investigating the effect of exogenous sugars on the yields of any plant specie in a hydroponic environment. Given our understanding of plant physiology, any positive effects related with anecdotal use of sugars are most likely related with positive effects in the rhizosphere that are linked with improved production of substances that elicit plant growth in the root zone by favorable microbes. This is mainly because it is already well established that transport of sugars within plants from the roots to the shoots is incredibly inefficient, so any contribution of the roots to sugar uptake will be completely dwarfed by the actual production of sugars from carbon dioxide in the upper parts of the plant. It is not surprising that no one seems to want to do a peer reviewed study of a phenomenon whose outcome is already largely predictable from the accepted scientific literature.

If you're interested in the use of sugars in hydroponics, it is probably more fruitful to focus on microbe inoculations instead. Sugars themselves are bound to provide no benefit if they are not coupled with a proper microbe population and,

even then, you might actually have all the benefits without any sugar applications as the microbes can be selected and fed by plant root exudates themselves in mature plants although sugars might provide some benefits in jump starting these populations, particularly in younger plants. Also, bear in mind that there is also a very high risk of stimulating bad microbes with the use of sugars, especially if oxygenation is not very high.

Controlling pH in hydroponics using only electricity

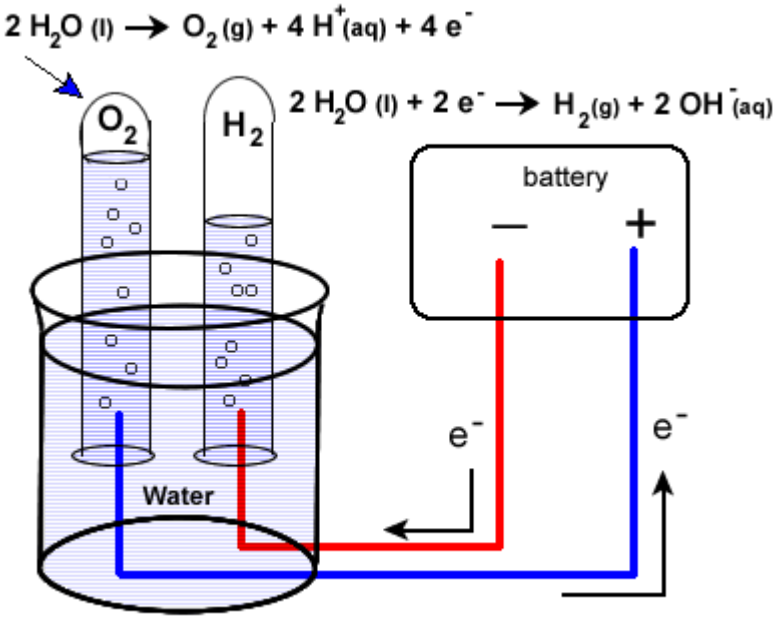
The ability of plants to assimilate nutrients changes as a function of pH. This makes maintaining the pH of nutrient solutions within an acceptable range – most commonly 5.8 to 6.2 – one of the most important tasks in a hydroponic crop. This is commonly done with the addition of strong acids or bases to decrease or increase the pH when it drifts away from the intended value. This requires either manual monitoring with careful addition of these substances or automated processes using pumps to ensure the pH always remains at the correct value. However both of these methods lack fine control, require a lot of maintenance and monitoring and can lead to costly mistakes. Today I want to discuss an alternative method that relies on a completely different idea to control pH, the idea that we can oxidize or reduce water using electricity to achieve changes in pH. **Yes, you can change pH using literally only electricity**.



A modern anion exchange membrane. Fundamental to the idea of an electricty-only pH control system

Let’s start by discussing pH and talking about how it is changes. The pH of a solution is calculated as -Log(|H^+|) where |H^+| is the molar concentration of H^+ ions in solution. In water, the dissociation constant 1×10^{-14} (at 25C), always needs to be respected, so we always know that the product of |H^+| and |OH^-| needs to give us this number. When you add acids you increase |H^+| conversely |OH^-| decreases and the pH goes down, when you add bases |OH-| increases, |H+| decreases and the pH goes up. *In simpler terms everything you need to decrease pH is a source of H^+ and everything you need to increase pH is a source of OH^-*.

This is where electrochemisty gives us the simplest solution we could hope for. Water can be oxidized or reduced. When you run a current through water – above the minimum required voltage – water splits into hydrogen and oxygen molecules. In the image below you can see how the water oxidation reaction generates H+ ions while the reaction on the right generates OH- ions. When you do this in a single cell – as shown below – the H+ ions generated at the anode react with the OH- ions generated at the cathode and the pH of the solution remains neutral while oxygen is produced at the anode and hydrogen is produced at the cathode.



The image above shows the half reactions involved in the oxidation (left) and reduction (right) of water.

However, we can take advantage of ion exchange membranes to separate these two processes, allowing us to control where each reaction happens and where the acid or base is generated (preventing them from just mixing and neutralizing). As a matter of fact, all we need is to have an electrode in our nutrient solution and another electrode in an auxiliary cell, separated from our nutrient solution by an ion exchange membrane. This concept is actually not new and was already proposed in a 1998 paper to control pH in hydroponic systems. Although it was never tried in a production system, all the concepts were validated and were shown to perform adequately in test solutions.

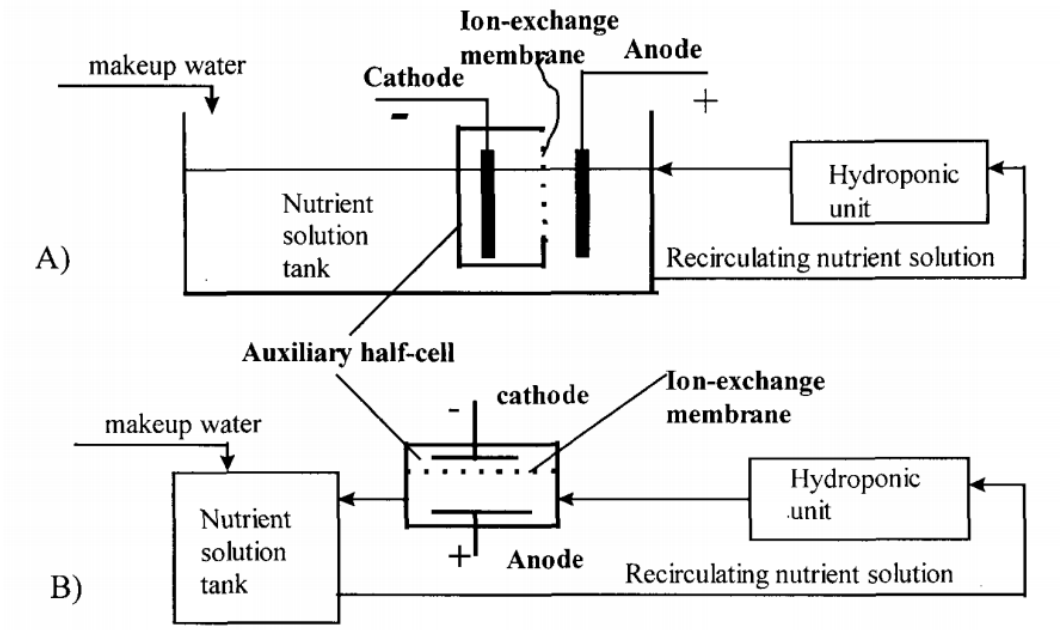


Image taken from [this paper](), which discussed the topic of electrochemical pH control in hydroponic systems at length.

One of the big challenges of this setup is that the cathode side involves hydrogen gas evolution – which could be dangerous – but can be completely avoided by replacing the cathode's half reaction with much more benign chemistry. As an example – also suggested in the paper above – you can replace the cathode half-cell with a copper sulfate solution with a copper electrode, with an anion exchange membrane. This would allow you to have your reduction reaction be the reduction of copper onto a copper place, which is a very tame reaction. Since the membrane only exchanges anions you would only have sulfate go to your nutrient solution, which is a benign anion in hydroponic culture. This of course means that your half-cell electrode and solution would need to be replaced with time, but this is completely independent from the control process (much more like refilling a tank of gas). The anode would only evolve oxygen in your nutrient solution, which is a potentially beneficial side effect.

Using a copper sulfate half-cell would however limit the control system to lower pH but this is not a problem since this is the most commonly used operation in hydroponics (very rarely do people have to increase the pH of their solutions).

If a proper venting system or catalytic recombination system is used on the cathode side you could also go with the simple water oxidation/reduction route and be able to increase or decrease the pH using basically, pure electricity.

I am definitely planning to build one of this setups in the future. Coupled with modern sensors and micro controllers this could make it extremely easy to maintain very fine control over the pH of the solution, compensating – in real time – all the changes in pH carried out by plants without the risk of heavily over or under compensating (as it happens when you use acid/base additions).

Cheap DIY high power LED grow lights: Introducing the Zip-tie lamp

Make sure you also read this post, where I studied the PAR of these lamps and realized they are not as good as I thought!

Several months ago I wrote a post about using high power LED cobs that do not require an external driver in order to build a high power DIY LED lamp. However I hadn't built a practical lamp using these cobs at that particular point in time so I just gave a general idea of why I would use these diodes and how the particular lamp setup would work. Today I want to talk about how to build one of these lamps in practice using an aluminum heat sink, a 150W warm white LED cob, a fan and some zip ties. The setup lacks the use of any adhesives and should provide you with roughly a 40-50% equivalent of a 1000W HPS. With two of these lamps you should be able to run the equivalent setup to 80-100% of a 1000W HPS in terms of PAR

with around 60% less power consumption.



The idea of this post is to help you build a very affordable DIY lamp. However please note that this lamp involves work with mains voltages which are dangerous. Please familiarize yourself with all the precautions needed when working with high voltages. All the information herein in is provided as-is for educational purposes with absolutely no guarantee, either expressed or implied.

To build this lamp – showed above – you will need these materials (note that if your country uses another voltage you will need to buy the appropriate pieces for the voltage in your country):

- Warm white 150W LED cob
- 200x60x30mm aluminium heat sink (2 needed)
- 110V-120V AC fan
- Nylon zip ties 30cm
- Cable and wall connector
- Thermal compound (optional)

Initially I wanted to build a lamp using a high power warm white LED cob by gluing the cob to the heatsinks using a thermally conductive glue. However the problem with this is that these glues very permanently bind the cob to the heatsink so if for any reason the cob fails you would lose the heatsinks because the cob would be bound to them. For this reason I decided to use zip ties instead, which provide an easy way to secure the entire ensemble and allow you to easily replace any failing part rather quickly. I used nylon zip ties but you can also use stainless still ones if you want the setup to be more resilient (although things will be harder to cut if you make a mistake).

To assemble the lamp I basically used 4 zip tie lines two horizontal and two vertical. For the lines that go the width

of the heat sink I just had to use one zip tie but for the other two lines – that also go above the fan – I had to use two zip ties for each line (you can connect one zip tie to another to have a larger zip tie). You need to tighten the zip tie very hard to ensure the cob is in direct contact with the aluminum along all its length, you can also use some thermal compound (like the one you use for CPUs) between the cob and the aluminum heat sink for maximum heat transfer. The pictures below show you a bit better how I performed the entire assembly. *When putting the fan on top of the heat sinks make sure the airflow is towards the heatsink (flow arrow in the case pointing down) and that the fan can spin freely).*





Finally I connected the cob directly to the AC line by soldering the appropriate live/neutral cables to the connectors at the left size of the cob (in the above picture). I then covered the soldered spots with silicon glue to ensure that the connections were as electrically isolated as possible. Make sure you solder as small portion of wire as possible and make sure the wire makes absolutely no contact with the aluminum heat sink or you will have a short. I also soldered the fan cables to the live/neutral as well since the fan can be driven directly by AC as well.

Since you have the zip ties you can also use them to hang the lamp, you can also add screws to the fan screwing ports and use those to hang the lamp from the ceiling. When I turned on this lamp its power consumption was around 220W – measured directly from the wall – meaning that it consumed a bit more power than what was advertised (which is not uncommon for these cobs). Since my voltage is a bit higher than 110V – which is the minimum rating for this cob – I actually get a slightly higher light/heat output than someone using it at a lower voltage. The fan – which takes around 12-15W on its own,

also contributes to this consumption level.



When you power on this lamp – image above (sorry about the camera not being able to handle the light intensity) – you'll immediately notice how the heat sink starts to heat up. I have tested the lamp through 2 hours of continuous operation up until now and the heat sink reached a stable temperature of around the 120°C (~ 250F), the final temperature you reach will of course depend on your ambient temperature and how well you assemble the components. It is however very important for you to test each one of these lamps for 12/24 hours to ensure that they don't heat up excessively. *Nylon will melt at around 220°C so you definitely don't want your lamp to ever reach even close to that temperature (to be safer you can use stainless steel zip ties)*. However it is very likely that the LEDs will burn out way before this happens if your temperature rises too far. You can also add a second fan or use a larger heat sink if your temperature is too high.

In the end the setup is extremely simple to build and you can get roughly 40-50% of a 1000W HPS with one of these lamps. With two of these lamps you will run at around 450W which is 55% less power than an equivalent HPS setup. Although heat generation is no joke here, it is indeed much less than the comparable heat output of a 1000W HPS. With a cost of less than 80 USD per lamp you will be able to build these lamps at a far lower cost than the very expensive grow lights you can get online (which can often go for thousands of dollars for a single 1000W HPS equivalent). *If you read my earlier post you will notice that I previously thought you needed 4 cobs to reach the equivalent of a 1000W HPS, turns out you only need two 110V cobs running at 120V!*

I have made some PAR, lux and temperature measurements but I want to keep those for a future post where we will look at some of the spectral and thermal characteristics of this lamp

vs other lamp types.

Potassium concentration and yields in flowering plants

From the different nutrients that are needed by plants we have known for more than 4 decades that potassium is of critical importance to flowering/fruiting plants. Potassium is one of the most highly limited nutrients in soil due to its high mobility and great increases in yields have been achieved with both potassium fertilization in soil and the use of properly balanced nutrient solutions containing enough potassium in hydroponics. But how important is potassium and what is its ideal concentration in hydroponic nutrient solutions when growing flowering plants? Today we are going to take a look at the scientific literature about potassium and what the optimum levels of potassium for different flowering plants might be in order to maximize yields.

There are many studies in the scientific literature dealing with the effect of potassium on various flowering plants. Earlier evidence from the 1980s pointed to optimum concentrations of potassium being close to the 160-200 ppm range. The book “mineral nutrition” by P.Adams (here) summarizes a lot of the knowledge that was available at the time and shows that for the growing techniques available at the time using greater concentrations of K was probably not going to give a lot of additional benefit.

However newer evidence from experiments carried out within the past 10 years shows that optimum potassium concentration might

depend on a significant variety of factors, from which media, other nutrient concentrations and growing system type might play critical roles. For example study on strawberries in 2012 (here) showed optimum concentrations of K to be around 300 ppm for strawberries and the optimum media to be a mixture of peat+sand+perlite (image from this article included above).

Evidence from experiments on tomatoes (link here and image from this article above) also shows that for tomatoes the actual optimum concentration of K might actually be larger under some condition with the optimum in this study in terms of fruit quality and yields being 300 ppm. In this last case the tomatoes were grown using a nutrient film technique (NFT) setup. However there have also been studies under other growing conditions – like this one on reused pumice – which shows that increasing K concentrations to 300ppm can actually have detrimental consequences. In this case tomatoes fed at 200, 290 and 340ppm of K had very similar results when using new substrate but the old substrate heavily underperformed when high K concentrations were used.

Papers published on the effect of different K concentrations in melons (here) and cucumbers (here) also point to optimal concentrations in the 200-300 ppm range and for the optimum N:K ratio to be between 1:2 and 1:3 for these plants. This is probably the reason why you will often find suggested nutritional guidelines for flowering plants – like those below taken from here – mostly suggesting K concentrations in the 250-350ppm range. However you will often find that they directly contradict research papers, like this guideline suggesting K of 150 ppm for strawberries while we saw in a recent paper that 300ppm might be better. This is most probably due to differences in the sources used which might have used different growing systems or plant varieties which responded to other conditions better.

All in all the subject of K concentration in hydroponics is no simple one. Using low K will limit your yields tremendously but increasing your K very high can also harm your plants, especially depending on the type of media you are using. In general aiming for a K concentration between 200-250 ppm is safest but in many cases increases to the 300-400ppm range can bring significant increases in plant yields. A careful study of the available literature and the actual growing conditions that the plants will be subjected to will be key in determining what the best K concentration to use will be. Alternatively carrying out adequately designed experiments under your precise growing environment will help you carry out an evidence-based decision about what K concentration to use.

Five reasons why a dedicated hydroponic testing room is a great idea

Most commercial hydroponic setups completely lack testing environments. The most common reason for this is that commercial crops are meant to produce revenue and a testing environment means dedicating space, time and money into something that might not be as productive as the rest of the production facility. Furthermore a testing room implies that you will need to create a completely independent setup and hire someone who knows how to do research in order to ensure it is both adequate and fruitful. Although many people believe this not to be worth it today I want to talk about the five most important reasons why I consider that a testing room is

something incredibly useful to have as a part of your commercial growing facility and why getting one will probably pay off greatly for you going forward.



Testing product changes. Perhaps the first and most direct benefit to having a testing room is to ensure you can test product changes. It may be the case that your supplier for some particular fertilizer product or additive has ran out and you now want to test a new product to replace it. It may also be that you want to test how a product does compared to what you generally use but you don’t know if it does better or worse. Most growers are afraid of change because making facility-wide changes that won’t work could have huge financial consequences. A testing room ensures you can test safely and then roll-out changes slowly without having to risk your entire crop cycle to find out.

Optimizing what you currently have. Change is very rare across commercial facilities because growers understandably want to preserve their current results, even if some better results by making some change would be possible. This constraints growers from making incremental changes that might make their crops significantly more productive. By having a testing room you can optimize the setup you already have by making adequate research into optimizing things such as environmental or nutritional factors.

Trying potentially game-changing modifications from academic research papers. There are many papers published each year on how to increase the yields of hydroponic crops. Some of these papers offer somewhat risky and controversial changes that might not transfer well across species. However if something gives you the potential to increase your yields by say, 50%, it might definitely be worth trying across a testing setup. Obviously these things are too risky to try across an entire facility but a testing room would be perfect to help you try

these new and exciting modifications, potentially giving you a huge edge versus all the other people who will never try this.

Try new plant varieties. Usually growers try new plants without having a clear idea of how productive they are going to be under their growing setup. This means that you introduce a new variety with a huge question mark regarding its productivity and potentially financial benefit or cost. A testing room provides you with a risk-free way to test how a particular plant variety will perform under the exact conditions in your facility, potentially allowing you to make far less risky decisions when it comes to making planting changes in your facility.



Research new ideas. A final benefit you can get from a testing room is that you can research your own new ideas. With adequate experimental design even a small room with just 10 plants can be used to test some ideas to see how they affect plant growth. This means that you can develop your own in-house growing modifications that will make it much harder for others to compete with you. For example if you developed a secret foliar additive in your growing facility it would allow you to only use this for your own crops, without the industrial secret ever being used by your competitors.

Of course there are many other advantages to testing rooms but the above are just some of the wonderful things you'll be able to do if you have a testing room and someone trained in scientific research who can help you design experiments and get the most out of it. A testing room also doesn't need to be huge and even starting out with 10 plants can be a huge step in taking your commercial growing facility to the next level.